

## **MICRO-ACTUATOR FOR HARD-DISK DRIVE, AND MANUFACTURING PROCESS THEREOF**

### **PRIORITY CLAIM**

[1] This application claims priority from European patent application  
5 No. 02425407.0, filed June 20, 2002, which is incorporated herein by reference.

### **TECHNICAL FIELD**

[2] The present invention relates generally to a micro-electro-mechanical device, in particular a micro-actuator for a hard-disk drive, and a manufacturing process thereof.

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### **BACKGROUND**

[3] Various processes are known for manufacturing micro-electromechanical structures, such as micro motors or micro-actuators that can be used for fine position control of reading and writing heads in hard-disk drives.

[4] In particular, in more recent times, to prevent burdensome steps for  
15 removing buried sacrificial layers, it has been proposed to use two distinct semiconductor wafers: a first wafer is designed to house the microstructures, while a second wafer operates as a support for the microstructures and integrates the control circuits of the microstructures.

[5] EP-A-1 151 962, which is incorporated by reference describes a  
20 manufacturing process of the above-referred type, which uses integrated silicon plugs for electrically connecting the second wafer to the front of the first wafer, on which the electrical interconnections are formed. The rear of the wafer is, instead, fixed to a protective cap, a read/write head or a further wafer.

[6] The above known solution, albeit representing a considerable  
25 improvement over previous solutions, is still complex and entails high manufacturing costs.

[7] Therefore, a need has arisen for a micro-electro-mechanical device and the manufacturing process thereof which overcomes the disadvantages referred to above.

## SUMMARY

[8] According to an embodiment of the present invention a micro-electro-mechanical device and a manufacturing process thereof are provided.

## BRIEF DESCRIPTION OF THE DRAWINGS

5 [9] For an understanding of the present invention, preferred embodiments are now described, provided purely by way of non-limiting example, with reference to the attached drawings, wherein:

[10] FIG. 1 is a cross-section through a wafer of semiconductor material, during an initial manufacturing step, according to a first embodiment of the invention;

10 [11] FIG. 2 is a top plan view of the wafer of FIG. 1;

[12] FIGS. 3-9 are cross-sections similar to that of FIG. 1, showing successive manufacturing steps of the wafer according to an embodiment of the invention;

[13] FIG. 10 is a top plan view of the device of FIG. 9;

15 [14] FIG. 11 is a perspective view of a detail for fixing the device of FIG. 9 to a suspension of a hard-disk drive according to an embodiment of the invention;

[15] FIG. 12 is a perspective view of a detail of FIG. 9, according to a different embodiment of the invention; and

[16] FIGS. 13-16 are cross-sectional views similar to that of FIG. 1, showing  
20 successive manufacturing steps of the wafer according to a different embodiment of the invention.

## DETAILED DESCRIPTION

[17] Referring to FIG. 1, according to an embodiment of the invention a first  
25 wafer 1 comprising a substrate 4 of semiconductor material, typically heavily doped monocrystalline silicon (for example, an N-type substrate with resistivity of 3 mΩ/cm doped with antimony) having a first surface 5, underwent the steps for making trenches, as described in the above-mentioned patent application EP-A-1 151 962, which was previously incorporated by reference. In particular, the first wafer 1 is masked and etched to form deep trenches 2, here U-shaped, as shown in FIG. 2.

The deep trenches **2** surround biasing portions **3** of monocrystalline silicon and have a depth approximately equal to the final depth of wafer **1**, for example, 100  $\mu\text{m}$ .

Alternately, the deep trenches **2**, may completely surround the biasing portions **3** where it is desired to obtain electrical insulation of parts of the first wafer **1**.

5    **[18]**           Next, referring to **FIG. 3**, the trenches **2** are filled, either completely or partially, to form insulating regions **6**, for example of silicon dioxide. For this purpose, a silicon dioxide layer is deposited or grown, and is then removed from the first surface **5** of the first wafer **1**, for example by chemical-mechanical polishing (CMP).

10   **[19]**           Next referring to **FIG. 4**, the first surface **5** of the first wafer is coated with an insulating layer **10**, for example thermally grown silicon dioxide, and openings **11** are formed for the contacts. The openings are formed above the biasing portions **3** of the substrate **4**.

15   **[20]**           Next, referring to **FIG. 5**, electrical-connection structures are formed and include contacts **12** extending in the openings **11**, electrical-connection lines **13**, and contact pads **14** (only one of which can be seen in **FIG. 5**). The electrical-connection structures, for example of TiNiAu, have a gold finish, to facilitate bonding of the next head.

20   **[21]**           Next, referring to **FIG. 6**, a second wafer **18** is bonded to the first wafer **1**, to obtain a composite wafer **19**. In particular, the first wafer **1** is bonded on the side comprising the electrical-connection structures, leaving free the rear of the wafer **1**. Bonding is obtained through bonding regions of suitable material. For example, bonding regions **15** of dry resist can be deposited on the front of the wafer and, by masking and etching, be left at scribing lines **16**, as shown in **FIG. 6**. Alignment marks (not shown in **FIG. 6**) are moreover formed on the rear of the  
25   second wafer **18**, for subsequent identification of the position of the scribing lines.

30   **[22]**           Next referring to **FIG. 7**, the first wafer **1** is thinned out from the rear mechanically, for example by grinding, until the bottoms of the trenches **2** are reached, preferably until a thickness of approximately 100  $\mu\text{m}$  is obtained. In this way a second surface **7** is formed.

30   **[23]**           Referring to **FIGS. 8-10**, the first wafer **1** is now masked and etched by trench etching starting from the second surface **7** so as to define the desired

micromechanical structure, in this case a micro-actuator **20**. In one embodiment, second trenches **21** are dug first in the substrate **4** and next in the insulating layer **10** (if it has not been removed previously) so as to separate, from the rest of the substrate **4** (hereinafter referred to also as bulk **30**), a mobile region **22** formed by a platform **23** and by a plurality of mobile electrodes **24**. The mobile electrodes **24** are comb-fingered with fixed electrodes **25**, which extend from the biasing portions **3** of the substrate **4** surrounded by the insulating regions **6**. In particular, as a result of the trench etching, the biasing portions **3** are electrically insulated from the bulk **30**, since they are delimited by a part of the insulating regions **6** and, towards the platform **23**, by a second trench **21**.

**[24]** The platform **23** is connected to the bulk **30** through elastic connection regions (hereinafter defined as springs **31**), and the electrical connection lines **13** leading to the contact pads **14** extend above the springs **31**.

**[25]** Referring to **FIG. 9**, the wafer **1** is cut into dies **33**. In this step, the bonding regions **15** are removed, and the dies **33** are separated from the second wafer **18**. Then, a ceramic body, referred to as slider **35** and carrying a read/write transducer (not shown), is bonded onto the platform **23** in a per se known manner. In addition, contact pads **36** on the slider **35**, in electrical connection with the read/write transducer, are soldered to the contact pads **14** using low-melting material **37**.

**[26]** Referring to **FIG. 11**, the connection lines **13** can terminate at contact pads **41**, which are soldered to respective pads provided on a suspension **42**. In the embodiment shown in **FIG. 11**, the top side of the die **33**, which carries the slider **35**, is fixed on the rear side of the suspension **42**, which is provided with an opening **46**, through which the slider **35** can pass (see, for example, EP-A-977 180, which is incorporated by reference). Thereby, the crosswise encumbrance of the suspension/micro-actuator/slider assembly is reduced to a minimum, and the system is particularly suited for meeting the increasingly stringent requirements dictated by the need to reduce space between the disks in hard-disk drives.

**[27]** Referring to **FIG. 12**, in one embodiment, each biasing portion **3** is connected to a single fixed electrode **25**; in general, however, the biasing portions **3** can be connected to any number of fixed electrodes **25** that are to be biased at a same potential, according to the existing space and layout requirements.

[28] Still referring to **FIG. 12**, an insulating region **6** is formed by insulating portions **6a** connected together by connecting portions **50** so as to define as a whole a wavy line, the ends of which terminate on a second trench **21** (**FIG. 10**). In particular, by careful design and alignment of the masks defining the first trenches **2** and the second trenches **21**, it is possible to get the connecting portions **50** to extend along the edge of the bulk **30** of the wafer **1**, thus separating the biasing portions **3** from one another. This solution can obviously also be applied to the case where each biasing portion **3** is connected to more than one fixed electrode **25**.

[29] Referring to **FIG. 13**, and according to a different embodiment of the invention, after forming the first trenches **2** and filling them with the insulating regions **6**, the first wafer **1** is bonded to a second wafer **60**. The second wafer **60** comprises a silicon substrate **61** and an insulating layer **62**, for example of silicon dioxide. On the surface **63** of the second wafer **60**, there are provided connecting regions **64**, of a metal that is able to react at low temperature with silicon of the first wafer **1** to form a gold/silicon eutectic or a metallic silicide. Typically, the connecting regions **64** are of palladium, so as to form a silicide; alternatively, the connecting regions **64** can be of gold, when it is desired to obtain a eutectic. Next, the first wafer **1** is turned upside down so as to turn the first surface **5** towards the second wafer **60** and a low-temperature thermal treatment is carried out, for example at 350-450°C for 30-45 min. Thereby, the metal of the connecting regions **64** of the second wafer **60** react with the silicon of the first wafer **1**.

[30] Next, referring to **FIG. 14**, the first wafer **1** is thinned out from the rear by lapping, until the bottom of the insulating regions **6** is reached, preferably down to 100 µm. The first wafer **1** then presents a second surface **7** opposite to the first surface **5**.

[31] Next, referring to **FIG. 15**, the second surface **7** is coated with the insulating layer **10**, and the connecting regions **12**, **13** and **14** are formed thereon. Then, the first wafer **1** undergoes a trench etch, to define the micro-electro-mechanical structure, in this case a micro-actuator **20**, as already described above with reference to **FIGS. 8** and **10**.

[32] Next, referring to **FIG. 16**, the second wafer **60** is thinned out, for example by lapping, and then cut into dies using a stick foil. A slider **35** is bonded on the die thus obtained, as already described above with reference to **FIG. 9**.

[33] Advantages of the microstructure and the process described above  
5 include the following. First, the use of junction insulations and separation trenches traversing the entire thickness of the final wafer and the elimination of steps of removing sacrificial layers enable the microstructure to be obtained with a greater thickness than the one previously described. Consequently, the facing area of the mobile and fixed electrodes **24** and **25** is greater than the one that could be obtained  
10 hitherto and ensures a greater capacitive coupling between the mobile and fixed electrodes. It follows that the distance between them may be greater than the distance hitherto possible (4-5  $\mu\text{m}$  vs. approximately 2  $\mu\text{m}$  for current actuators).

[34] The greater distance between the electrodes means that any  
electrostatic particles attracted to the inside of the trench defining the micro-actuator  
15 (which typically has a size of 1-2  $\mu\text{m}$ , comparable to the size of defining trenches hitherto achievable and hence smaller than the gap so far obtainable), are less likely to short-circuit the mobile and fixed electrodes or block them.

[35] It follows that the current structure does not require a cap for protection and shielding from the particles, thus drastically reducing the costs of fabrication, as  
20 well as the total thickness of the microstructure.

[36] In addition, the greater thickness of the microstructure means that it is sturdier and less subject to failure, so enabling elimination of a supporting wafer (the second wafer **18** operates only as a handling wafer and is removed at the end of the fabrication operations, in the first embodiment) or the use of a supporting wafer of  
25 very small thickness (as in the second embodiment).

[37] Referring to **FIGS. 10, 11 and 16**, floating connections are not necessary for the electrical connection, in so far as all the parts can be reached by metal lines passing on the insulating layer **10**. In particular, the connections to the slider **35** can be formed to pass on the springs **31** for supporting the platform **23** and  
30 the mobile and fixed parts of the micro-actuator can be biased by usual contacts/connection lines.

**[38]** The manufacturing process of the microstructure is moreover simplified with respect to known processes and in particular requires fewer masks, with a consequent reduction in the manufacturing costs.

**[39]** Referring to **FIGS. 10** and **16**, it is clear that numerous modifications and variations can be made to the microstructures and to the process described and illustrated herein, all falling within the invention, as defined in the attached claims. For example, although the embodiments shown involve the biasing of the fixed regions (fixed electrodes **25**) by regions insulated from the bulk, while the mobile regions (platform and mobile electrodes) are electrically connected to the bulk and are at the same potential as the latter, it is possible to make insulated biasing regions at one end of the springs **31**, for biasing the mobile regions, and further regions insulated by the insulating regions **6** or other insulating techniques, for biasing the fixed regions (fixed electrodes **25**). Alternatively, if the fixed regions are biased at the same potential as the bulk, the insulating regions **6** can be provided only for the biasing regions of the mobile part.

**[40]** Furthermore, although the illustrated structure has actuating electrodes **24, 25** on two different sides of the platform, it is possible to provide actuating electrodes on just one side thereof.

**[41]** Embodiments of the invention may moreover also be applied to microstructures of a rotary type, with a circular platform having electrodes extending radially, and to microstructures with different functions, for example sensors and accelerometers.

**[42]** Referring to **FIGS. 8** and **10**, in one embodiment, bonding regions **15** can also be provided on the front of the portions of the first wafer **1**, which are to be removed (areas between the electrodes **24, 25**, where there are sufficient distances) and possibly at the centre of the platform **23**, which need not necessarily be "full", but can have holes or cavities, through which it is possible to access the bonding regions **15** for their removal.

**[43]** Referring to **FIG. 10** a micro-actuator **20** according to any of the above-described embodiments may be included in a read/write head assembly, which in

turn may be included in a disk drive such as a magnetic hard-disk drive. And such a disk drive may be included in an electronic system such as a computer system.

**[44]** The preceding discussion is presented to enable a person skilled in the art to make and use the invention. Various modifications to the embodiments will be readily apparent to those skilled in the art, and the generic principles herein may be applied to other embodiments and applications without departing from the spirit and scope of the present invention. Thus, the present invention is not intended to be limited to the embodiments shown, but is to be accorded the widest scope consistent with the principles and features disclosed herein.